DOI 10.5162/EUROSENSORSXXXVI/OT4.235

A High-Performance Mode-Localized Vacuum Gauge Based on T-Typed Piezoresistive Pickup

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Summary:

This paper presents a high-performance MEMS vacuum gauge based on mode localization within 2 – 1000 Pa from 0 °C to 60 °C. Since the noise of the pickup signal decides the maximum amplitude ratio output and the sensitivity. A two-degree-of-freedom weak coupling resonator based on H-typed DETF resonator and T-typed piezoresistive strain pickup is developed. Results show that it has the advantages of large power-handling and high signal-to-noise ratio. The device equipped with that has a sensitivity of 280000 ppm/Pa and a lower limit of 2.00 Pa which is superior to previous works.

Keywords: High sensitivity, mode localization, vacuum gauge, piezoresistive strain gauge, temperature characteristics

Background, Motivation and Objective

Vacuum gauge is widely used in industrial measurement and control. And sensitivity is an eternal topic in the sensor's design because high sensitivity usually means high resolution or detection threshold [1]. MEMS resonator-based gauges have a long history, and the sensitivity and lower limit of these gauges are limited by the diaphragm parameters and gas damping which is difficult to further increase [2].

Mode localization is a magical phenomenon in weak coupling resonator (WCR) systems. It can enhance the sensitivity of resonators to stresses while amplitude ratio (the ratio of vibration amplitude of resonators, AR) is selected as the output metric [1-2]. Theoretically, the sensitivity can be designed to be arbitrarily large in the case of a consistent amount of stiffness perturbation. In fact, the sensitivity and linear range are limited by the floor noise and signal-to-noise ratio (SNR) of the pickup signal.

In this paper, a high power-handling WCR and large SNR piezoresistive pickup are proposed. The basic characteristic of the WCR and pickup is measured, and the performance of the vacuum gauge is calibrated.

Description of the New Method or System

The structure of the gauge is shown in Fig. 1(a). The vacuum pressure pushes the diaphragm, and the diaphragm generates both positive and negative stresses. The resonators are placed on the above two zones to differential sense the pressure which can also mitigate the influence of the thermal stress [3]. A Silicon cap is bonded to the SOI wafer to fabricate the reference vacuum. As shown in Fig. 1(b), the WCR is composed of two T-typed DETF resonators coupled with a slender beam. The resonator is driven by an electrostatic comb finger and picked by a T-typed piezoresistive. The piezoresistive bar is perpendicular to the beam and is stretched and compressed when the resonator vibrates, so the resistivity is changed.

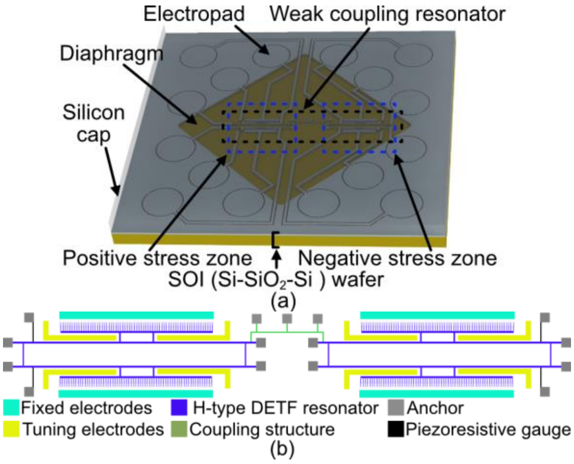

Fig. 1. (a) Structure of the vacuum gauge. (b) The structure of the H-typed DETF weak coupling resonator and T-typed piezoresistive pickup.

Results

The open-loop response of WCR is measured at the operating point (0 °C and 2.00 Pa) as shown in Fig. 2. The amplitude of the two basic modes cannot be tuned to 1.0 simultaneously because of the fabrication error, so only the out-of-phase mode is calibrated. The floor noise of Resonator2 (R2) is smaller than Resonator1 (R1) which helps obtain a large AR (R1/R2). Because the piezoresistive pickup is used [4] and the distance between the driving port and the pickup port is large in R2, the feedthrough is decreased. Finally, the peak-peak value of 21.2 dB and 28.4 dB of R1 and R2 is achieved which is larger than the widely used capacitance pickup [2, 5].

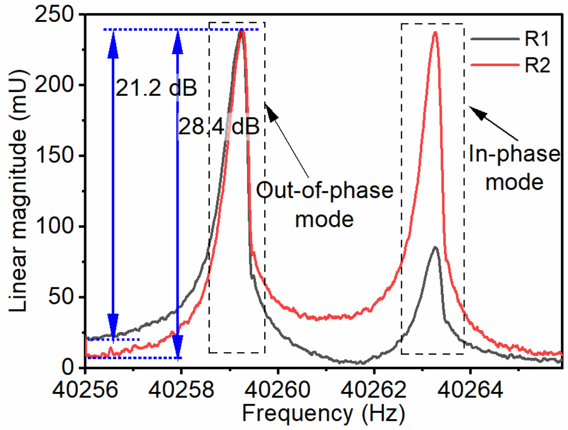

Fig. 2. The open-loop response of the weak coupling resonator.

The measurement of sensitivity in open-loop configuration is shown in Fig. 3. The pressure sensitivity achieves 280000 ppm/Pa (0.028 /Pa). The relationship between AR and temperature is a quadratic function because the variations of stiffness induced by the thermal stress also are quadratic. It can be concluded that AR increases with the vacuum pressure and temperature. However, the linear range of AR cannot be infinite because of the noise and power handling as described before. Therefore, the temperature is limited to a narrow range.

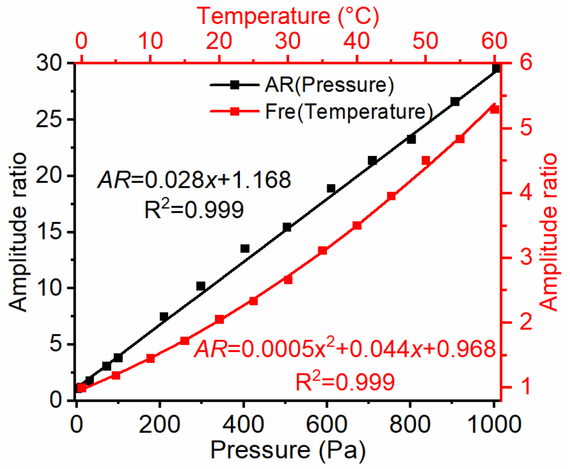

Fig. 3. The pressure and temperature sensitivity of frequency and amplitude ratio at the operating point.

As shown in Fig. 4, the device is calibrated from 0 °C to 60 °C. AR will be nonlinear while the temperature extends the range. Finally, the linearity is good within the range. The hysteresis error is ±1.2 % of the AR reading value (the blue bar in Fig. 4), and a lower limit of less than 2.00 Pa is achieved within the temperature range. The comparison of key performances with previous work is shown in Tab. 1.

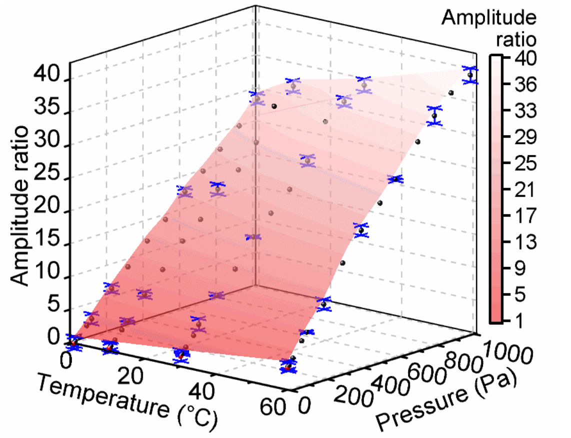

Fig. 4. The calibration results within 2.00 – 1000 Pa from 0 °C to 60 °C.

Tab. 1: The comparison of the key performance

Works	Pressure & temperature	Sensitivity & range of AR
Ref. [2]	100.0 – 1000 Pa −20 – 60°C	90000 ppm/Pa 1 – 9
This work	2.00 – 1000 Pa 0 – 60°C	280000 ppm/Pa 1 – 28

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